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Strangeness in the Central Region
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Larry McLerran
Theory Department MS-106
Fermilab P. O. Box 500
Batavia Il. 60510

I summarize recent work about strangeness in the central region as it might appear in ultra-relativistic heavy ion collisions. I argue that in the central region, strangeness is not a signal of the existence of a quark-gluon plasma, although an enhanced strangeness production might signal interesting dynamical phenomena. I argue that the strangeness in a quark-gluon plasma compared to that in a hadron resonance gas is not anomalously large for either the K/π ratio or the strange to non-strange anti-baryon ratios. I also argue that for the energy and baryon number densities expected in the fragmentation region of ultra-relativistic nuclear collisions, strangeness is not a signal of a quark-gluon plasma.

Section 1 : Strangeness and the Plasma

The degree of strangeness production in ultra-relativistic nuclear collisions has long been believed to provide a signal for the production of a quark gluon plasma.[1-3] The argument for this enhanced strangeness goes roughly as follows: In a quark-gluon plasma at high temperature, there are roughly equal numbers of up, down, and strange anti-quarks and quarks. The probability of forming a strange meson relative to that of a non-strange meson is therefore $1-(2/3)^2 \sim 5/9$ which is large compared to that observed in pp collisions $\sim 1/10$. The probability of forming a strange baryon is $1-(2/3)^3 \sim 2/3$ which is large compared to that expected for pp collisions.

An argument originally due to Redlich,[4] and later refined by Glendenning and Rafelski[5] casts a long shadow of doubt on this argument as far as mesons are concerned. The strangeness to entropy ratio reflects the degree of strangeness of a system more accurately than does the meson content abstracted from naive quark counting. The reason for this is that as the fluid produced in the central region evolves, entropy is conserved. It is the entropy which eventually determines the number of pions, and therefore controls the numerical value of the K/π ratio. As has been argued by Redlich and colleagues,[6] the strangeness to entropy ratio in a quark gluon plasma is less than that in a hadronic resonance gas for any reasonable temperature $T \sim 100$ Mev. In this sense, a hadronic resonance gas is stranger than a plasma.

The reason why a plasma is not as strange as a hadron gas is easy to understand. In a plasma, the contribution to the entropy is about 30%-40% due to gluons. In a hadron resonance gas, the entropy arises only from meson bound states which are composed of quark-antiquark pairs. The mesons are anomalously light compared to glueballs, since they are the Goldstone bosons of a spontaneously broken chiral symmetry. The gluon contribution to the entropy is therefore frozen out. Therefore in a range of temperatures where the effects of the mass difference of kaons to pions is small compared to the mass difference between glueballs and pions, the glue degrees of freedom are frozen out, and the relative amount of strangeness in a hadron gas is small compared to that of an ideal quark-gluon plasma.

The preceding argument does not apply to the case of strange baryons and anti-baryons. To see whether a quark-gluon plasma or a hadron gas is stranger, consider the following ratio

$$r = \frac{f^{plasma}}{f^{hadron}}$$

where f^{plasma} and f^{hadron} are the ratio of strange to non-strange baryons in the quark-gluon plasma and in a hadron resonance gas respectively. To estimate f^{plasma}, I took the statistical probability that three quarks formed a strange or nonstrange baryon weighted with a factor of $e^{-m_s/T}$ for each strange quark. I used a strange quark mass of 150 Mev. In the hadron gas, I considered all the strange and non-strange baryon resonances up to a mass of 1.5 Gev. The probability of occurrence of each species of baryon was weighted by $m^{3/2}e^{-m/T}$. The result of this computation is a value of $1.2 < r < 1.4$ for all temperatures between 100-300 Mev. The plasma is a little stranger than a hadron gas, but certainly not within the errors of this estimate. In the review of Muller and Rafelski, this ratio is approximately 2.[7-8]

In ultra-relativistic heavy ion collisions, especially in the fragmentation region, there is always finite baryon number density. Taking an estimate of the achievable conditions from the hydro-dynamical calculation of Kajantie, Raitio and Ruuskanen,[9] there is about a factor of 10 times more energy density in total than there is energy density stored in baryon number density. If this number is typical, then $\mu_B/T \sim 1/2$. For this small value of μ_B/T, the computations of Rafelski and Muller show that the quantity r is fairly slowly varying, and from their Fig. 7.3 b, I estimate only about a 25% change in this ratio r.

Although the relative abundance of strangeness in a plasma to that in a hadron gas is not dramatically large, the actual numerical value of the strangeness seems to be somewhat large. For example, for strange baryons, the abundance in a hadron gas as a function of temperature is

Ratio of Strange Baryons to Non-Strange

Ratio	Temperature
.3	100 Mev
.5	150 Mev
.7	200 Mev
.9	300 Mev

These ratios seem to be so large that an observation of the actual number may explore the degree of thermalization and dynamics of the central region. The dependence upon baryon density is also of interest.

A variety of computations have attempted to compute the K/π ratio in the central region.[10-12] All of these computations use entropy conservation, and relate the final pion multiplicity to the entropy.

The number of kaons are determined from a number of different assumptions about the initial conditions, and various approximations about the production and annihilation rate of strange particles. There is a wide range of estimates of the annihilation cross section in the hadron gas phase. The first estimate of this type invoked no specific hydrodynamic model. In the computations of Mekjian and Kapusta, and of Matsui, McLerran and Matsui, 1+1 dimensional hydrodynamic models were used. In the computation of Kajantie, Kataja, and Ruuskanen, a 3+1 d hydrodynamic simulation is used. All computations agree that the K/π ratio is .2 - .4. This is somewhat larger than the value typical for pp collisions, but not dramatically larger.

(There has been some confusion about the dispute between various authors concerning the computation of the scattering time for annihilation of strangeness in a quark-gluon plasma. In the computation of Matsui, McLerran and Svetitsky,[11] there is a claim of a factor of 3 discrepancy between the value of the relaxation time quoted there and by Rafelski and Muller.[3] In fact, there is such an error in the paper of Rafelski and Muller,[3] but when the relaxation time was put into dynamical computations, another factor of two mistake was made, making the actual disagreement between used scattering times numerically quite small. Such a small uncertainty in the relaxation time, even by a factor of three, is certainly within the uncertainties of theoretical estimates.)

As a warning concerning the use of strangeness as a signal of plasma formation, we can consider the example of p_t distributions of kaons and pions. Due to an argument of Shuryak,[13] we expect that heavy flavors are enhanced at large p_t. This argument is a consequence of the fluid expansion of matter produced in an ultra- relativistic nuclear collisions. If a fluid expands, the fluid has a transverse expansion velocity v. All particles expand with this same velocity. Therefore, more massive particles acquire more transverse momentum than do light particles. The p_t distribution of heavy particles is therefore broader. If this is true, then, strangeness may be enhanced in the large p_t tails of distributions, even though the integrated strangeness yield might be modest. The strangeness yield at large p_t is therefore a signal for interesting dynamics, but not of a quark-gluon plasma.

In conclusion, I see no compelling reason to believe that in the central region, strangeness is a signal for a quark-gluon plasma. Anomalous strangeness may however represent interesting dynamical effects. Even in the fragmentation region of ultra-relativistic nuclear collisions, the baryon densities achieved do not seem to invalidate these simple central region estimates. If it is possible somehow at some energy to form a baryon rich cold plasma, then there might possibly be a signal for the quark-gluon plasma, in accordance with the computations of Rafelski and Muller.(8)

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